BUILDING RESILIENT COASTS: EXPOSING HIDDEN HAZARDS RESULTS IN MORE RESILIENT INFRASTRUCTURE

By Nancy Hoene, Minnesota Sea Grant

Obvious hazards that threaten coastal communities are usually forces of nature—hurricanes, earthquakes, tsunamis, shoreline erosion, bluff failures, and the like. But a hazard that is commonly overlooked or underestimated is coastal infrastructure deterioration. One specific form of deterioration is corrosion, which also occurs naturally when a material (usually a metal) reacts to its environment. It can damage infrastructure in coastal areas—bridges, piers, docks, harbor buildings, power plants, off-shore platforms, pipelines and other structures—threatening public safety, disrupting operations, and requiring expensive repair or replacement. Corrosion impacts safety, the economy, and the environment, and part of coastal communities' resiliency is mitigating or eradicating its effects.

The Federal Highway Administration reported in 2007 that the annual cost of corrosion was $430 billion nationally, or about three percent of Gross Domestic Product. That's significant, if not all coastal.

Corrosion takes many forms and each coastal region presents different causal agents. Often, other government entities turn to Sea Grant for assistance, and Sea Grant partners with non-governmental organizations or the private sector in providing non-advocacy, science-based understanding and solutions.

For example, the Federal Emergency Management Agency (FEMA) turned to North Carolina Sea Grant's coastal engineering specialists for help when they realized the metal connectors they recommended to hold buildings together during hurricanes were subject to serious corrosion.

North Carolina Sea Grant used historical records from a local firm, La Que Corrosion Services, to identify the serious consequences of corrosion for buildings near the ocean. Sea Grant funded ten years of full scale exposure testing and subsequently wrote FEMA's Technical Bulletin, *Corrosion Protection for Sheet-Metal Connectors* (TB8-96 or www.fema.gov/MIT/techbul) which is distributed to builders, designers, and coastal communities nationwide.

In keeping with its strategic aims, Sea Grant has taken the lead in convening groups to address corrosion problems, funding research to identify the extent of the problem, isolating causes, and offering solutions. As you read further, you will see how Sea Grant efforts have led to innovative processes, resilient products, new legislation, as well as outreach workshops and seminars.

For years, corrosion research focused on saltwater marine environments, leaving a gap in research. Then in 2004, when underwater sheet piling supporting many of the freshwater docks in the Duluth Superior Harbor in Lake Superior were found to be corroding at an accelerated rate, Minnesota and Wisconsin Sea Grants organized a team of experts to investigate the unusual freshwater and coldwater corrosion in Lake Superior. If the structural integrity of the docks and loading facilities were to continue corroding rapidly, the failing steel would have to be replaced at a cost of $1,500 or more per linear foot, or about $120 million.

"We immediately focused on two very different study directions. One direction was determining the cause of highly unusual freshwater accelerated corrosion, while the other was studying ways to rehabilitate or repair those structures already in peril," said Gene Clark, Coastal Engineering Specialist, Wisconsin Sea Grant.

In collaboration with the Duluth Seaway Port Authority and the U.S. Army Corps of Engineers, Minnesota and Wisconsin Sea Grant convened experts, consultants, engineers, and scientists to examine potential causes, recommend mitigation measures, and identify next research steps for the 13 miles of steel sheet piling corroding throughout the harbor. In subsequent tests—micro-biologically influenced corrosion (MIC) lab investigations (see *Types of Corrosion*)—bacterial communities on the corroded steel in the most affected part of the harbor were found to be different from bacterial communities in less affected areas just outside the harbor. Bacteria that oxides iron (from $Fe2+$ to $Fe3+$) was isolated from the corroding structures. Preliminary research indicated a unique combination of bacteria, water chemistry, and ice scouring were responsible.

Madeline Gotkowitz, Univ. of Wisconsin-Extension

Concurrently, testing continued on a collection of coupons (steel plates) from trays placed throughout the harbor to investigate the rate of corrosion and possible coatings that could protect the steel. Both uncoated and coated coupons are removed, inspected, and replaced. Ice abrasion and impact test samples, installed in 2008, are also being pulled, inspected and then returned for another year. Additional linear polarization testing will be conducted in 14 locations. These and other tests are helping determine the causes of corrosion and most importantly, methods for saving the steel structure that's left on existing docks. The Great Lakes Network of Sea Grant programs were ready and able to assist in providing science-

Types of Corrosion

Generalized Corrosion: a well-distributed, low level attack on the entire metal surface with little or no localized penetration… the least damaging type of corrosion.

Pitting Corrosion: localized deep penetration of a metal surface with little general corrosion around it. It is caused by surface deposits, electrical imbalance, or some other initiating mechanism. Pitting corrosion may include: crevice corrosion, waterline attack, under deposit attack, concentration cell or erosion corrosion.

Galvanic Corrosion: an aggressive, localized form of corrosion due to electrochemical reaction often found between two dissimilar metals in an electrically conductive environment. It occurs because the electronegative material (the anode) is attacked by the electropositive material (the cathode).

MIC Corrosion: microbiologically influenced corrosion is deterioration caused by microorganisms on the surface and under specific environmental conditions. MIC corrosion usually signals a severe threat to the entire system. It produces large deep pits due to the microorganism using iron as an energy source, then producing corrosive metabolic by-products.

Erosion Corrosion: the gradual and selective deterioration of a metal surface due to mechanical wear and abrasion.

CUI Corrosion: corrosion under insulation is a threat to holding tanks or systems operating at lower temperatures in humid environments. Outdoors, moisture, rain, snow or ice can penetrate the insulation and cause physical damage. CUI usually remains hidden until severe damage has occurred.

Concentration Cell Corrosion: when the surface is exposed to an electrolytic environment where the concentration of the corrosive fluid or the dissolved oxygen varies.

Crevice Corrosion: occurs at places with gaskets, bolts and lap joints where crevice exists. Crevice corrosion creates pits similar to pitting corrosion.

See corrosion photo gallery at:
http://www.corrview.com/gallery1.htm

based experience and non-advocacy testing of applicable demonstration projects. Project reports, fact sheets, and photos can be found at: http://seagrant.wisc.edu/CoastalHazards/Default.aspx?tabid=1539

As a major player in corrosion research—along with the U.S. Navy, the National Academies and NACE International (an association of corrosion engineers in the private sector), Sea Grant is behind a number of innovative processes that fight the problem.

With a grant from NOAA Sea Grant and Maritime Administration (MARAD), the University of Maryland's Chesapeake Biological Laboratory tested the ability of the Venturi Oxygen Stripping™ to kill or deactivate harmful microscopic aquatic organisms. Lab-scale testing proved effective, as well as treatment at high flow rates. Results showed that the system is able to meet the International Maritime Organization (IMO) standards.

Ohio Sea Grant funding is making it possible for the University of Akron to develop effective, non-toxic, environment-friendly antifoulants, by understanding a natural product, zosteric acid (ZA). ZA deters attachment of many microorganisms, algae, barnacles and tubeworms and interacts with cells. Traditional heavy metal-based anti-fouling paints release toxins that create environmental concerns. The use of non-toxic or less toxic marine products as antifoulants represents a promising new approach.

In California, Florian Mansfeld at University of Southern California (USC) Viterbi School of Engineering (whose early work in corrosion was funded by USC Sea Grant) was among the first to show that if the problem with MIC corrosion is biofouling, then the solution may be the opposite: bacteria that can protect metals. *Shewanella oneidensis*, a bacterium that metabolizes metals and changes their chemical structures by giving them electrons, proved to be the best of these and the process is called "microbiologically influenced corrosion inhibition," or MICI.

In order to make a difference, research results must be applied by decision-makers, local officials and the public. Sea Grant is instrumental in delivering corrosion education and outreach. For instance, Washington Sea Grant, Jefferson Education Center and Washington State University (WSU) offer workshops for marine professionals on galvanic corrosion, crevice corrosion, types of anodes, corrosion damage from stray current, and more.

Sea Grant's corrosion research also informs public policy. Congressman Michael Conaway (R-TX) and Congresswoman Betty Sutton (D-OH) introduced H.R. 1682, *Bridge Life Extension Act of 2009* which could have far-reaching impact on the integrity of the nation's bridges. It is estimated that more than 45,000 bridges are in danger of serious structural issues related to corrosion. Sea Grant-funded research is bound to impact the discussion.

As coastal communities in the United States move forward, applying science and technology to the reduction of coastal hazards and preparing coastal communities to be resilient in the face of disasters, NOAA Sea Grant (and its partners) are solving the underlying challenges that coastal infrastructure corrosion presents. ❖